

Effective Methods and Emerging Trends in Engineering Education

Abdelkrim Haddad

*Mechanical Engineering Department,
PO Box 840, Makkah University, Makkah, Saudi Arabia.*

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يلعب التكوين الهندسي دورا مهما في التنمية الاقتصادية و الاجتماعية للأمة وكذا سمعتها بين دول العالم. التاسع عشر والعشرين تفرعت العلوم الهندسية إلى تخصصات مختلفة، وسيكون القرن الواحد والعشرين زمن الإدماج نظرا لأن تخصصات علوم الهندسة بدأت تتجمع. زيادة على ذلك فظهور العولمة الاقتصادية تتطلب احتياجا حقيقيا للمهندسين الحاليين الذين عليهم أن يعترفوا بأنه مهما كانوا لامعين وأذكياء وشجعانا فهذا لا يكفي، إذ عليهم اليوم كسب مهارات تمكنهم من الدفاع وبيع أفكارهم الحولية التقنية وكذا مهارات الاتصال الشفوية والكتابية نة وظيفية مرموقة. وعلى الجامعات تقديم التوجيه والمناهج الدراسية الملئمة لإنجاز الأهداف المرجوة لكل الطلاب. ومن مهام الجامعات كذلك ابتكار طرق جديدة للتدريس والتدريب بطريقة مستديمة وكذا عرض المعرفة بطريقة محفزة مع ضمان اجتازها. يراجع البحث الحالي بعض مظاهر نظام التعليم الهندسي التقليدي في بلدان شمال إفريقيا وبعض الدول الأوروبية (فرنسا وألمانيا) ويقدم البحث أيضا التوجهات المستقبلية لهذا التعليم كما يناقش الصفات الأساسية لمهندس القرن الواحد والعشرين. أخيرا تهتم الدراسة بمناقشة مختلف مناهج التعليم الهندسي وطرق تقييم نوعيته و مصداقيته.

الكلمات المفتاحية: الهندسة التربوية النوعية المصادقية.

Résumé

La formation d'ingénieur joue un rôle très important dans le développement économique et social d'une nation ainsi que sa réputation dans le monde. Au cours des 19^{ème} et 20^{ème} siècles, les sciences de l'ingénieur se sont divisées en disciplines spécifiques. Le 21^{ème} siècle sera plutôt celui de l'intégration, Les disciplines des sciences de l'ingénieur commençant à converger. En plus, l'émergence de la mondialisation de l'économie nécessite un besoin réel de sensibilisation des étudiants Ingénieurs d'aujourd'hui qui doivent reconnaître qu'étant brillant, techniquement intelligent et motivé ne suffit plus. Ils doivent développer des capacités leur permettant de défendre et de commercialiser leurs idées-solutions technologiques ainsi que celles de communication orale et écrite afin de pouvoir aspirer à une carrière fructueuse. Les universités doivent fournir une assistance-aide ainsi qu'un cursus adéquats afin de rendre possible l'accomplissement de ces objectifs aux étudiants. Elles doivent aussi développer d'une manière continue des approches innovatrices de la formation ainsi que permettre la transmission du savoir d'une manière motivante et assurer sa rétention. La présente étude fait un tour d'horizon du système traditionnel de formation d'ingénieur au sein des pays d'Afrique du nord et certains pays Européens (France et Allemagne). Elle présente aussi les tendances émergentes de cette formation et discute les caractéristiques principales de l'Ingénieur du 21^{ème} siècle. Les méthodes d'enseignement ainsi leur évaluation qualitative et leur certification sont aussi discutées.

Mots clés : ingénierie; éducation; approches; qualité; certification

Abstract

Engineering education plays a very important role in the social and economic development of a nation as well as its standing in the world. During the 19th and 20th centuries, engineering "disintegrated" into specific disciplines. The 21st century will instead be a time of integration, as the various sub-disciplines of the sciences and engineering converge. Moreover, the emergence of the world economy has led to a real need to develop a global awareness in the minds of today's engineering students. They need to recognize that being bright and technically sound and motivated is not enough. They must also have skills to defend and sell technical ideas as well as excellent oral and written communication skills for a successful career. Universities must provide guidance and a curriculum making the achievement of this goal possible for all students. They

must also have to continuously develop innovative approaches to education delivery and training as well as offer knowledge in a motivating way and insure retention. The actual paper reviews some aspects of the traditional system of engineering education particularly in the North African countries as well as in some European countries (France and Germany). It also presents the emerging trends in engineering education and discusses the key characteristics of the 21st century engineer. Instructional methods and quality assessment and certification are also reviewed.

Key words: *engineering; education; approaches; quality; certification.*

1. INTRODUCTION

What is the public's general perception of an engineer? And what are the professional skills one needs the most to succeed as an engineer? Do people consider engineering as a profession or as a set of technical oriented job category? Are a strong math and science background, and a bachelor's degree in engineering enough to make him/her competitive in a workforce that is steadily advancing in technical expertise? Lack of a clear understanding of what an engineer does is not the sole problem; the engineering field is changing like it never has before. The technical advances of the 19th Century and the rapid changing demands of the socio-economic developments in the 20th Century greatly broadened the field of engineering and introduced a large number of engineering specialties. Moreover, with the development of sophisticated computers and software, some types of design activities which employed large number of engineers have become more like commodities. Computer simulation and design packages can often be applied to solving engineering problems, reducing the need for engineers, particularly engineers with the education presently provided.

Many of the new attributes engineers will need are not evident in current engineering curricula, and it is unlikely students will acquire these attributes without some guidance and practice. Under these conditions, it is time to reevaluate the traditional approach to engineering education consisting of a

math and science base followed by a tight focus on a specific engineering sub-discipline. Without sufficient knowledge of other disciplines, effective communication will be extraordinarily difficult in the multidisciplinary teams that will develop next-generation products or services. The role of the university is to develop new concepts in higher engineering education in order to prepare the students for the challenges imposed on them as engineers. In the engineering education community, a continual strive to improve the education provided to students is carried out. Currents efforts include programs to prepare a diverse cadre of engineers, increased accountability about how effectively engineering programs prepare engineering students, and an interest in preparing engineers to function in a global community with ethical and professional responsibility [1].

One option is for engineering education to embrace the concept that the first professional degree will be the MS degree. The BS degree will no longer include all the technical courses as well as the non-engineering courses (legal matters, social sciences, business administration, languages etc.). The MS degree will be the professional degree that will define the engineering specialty whereas the BS degree will provide the necessary background-education for the new engineer. Students interested in research may continue their studies with a research thesis as part of a program allowing them to obtain a PhD degree.

This concept will not succeed if effective instructional methods are not developed and applied. These methods would enhance student learning through interactive learning using trial-and-error exercises conducted at each one's speed, systematic approaches, simulations etc.

2. ASPECTS OF THE TRADITIONAL SYSTEM OF ENGINEERING EDUCATION

In spite of the fact that the total number of students studying in technical programs has been rising, their intrinsic quality has been decreasing and many students are not even interested in such programs. As a result, more and more students are dropping out and leaving their studies without any certificate. In the traditional system, university students aiming at a Diploma degree in engineering have to complete a study program generally consisting of two main parts. The first part focusing on basic theoretical and practical education takes about four semesters ending by a four weeks company internship.

The advanced study program of the engineering education takes on the average six semesters, the last part being a company internship in which the students are advised to spend twelve weeks in a company for gaining practical experience in subjects related to their specialization. Subsequently, a scientific research project, the Diploma thesis, is performed under scientific guidance four about four months. The grade of the nine semesters (five semesters in some cases [2]) and the grade for the Diploma thesis form the grade of the Diploma degree.

The average time required for obtaining the final degree of the "Diplôme Ingénieur" is usually about twelve to thirteen semesters, although the programs are designed such that students should obtain it within ten semesters. Possible reasons are failed tests and a *laisser-faire* attitude encouraged by the fact that there

are no tuition fees in Algerian universities. In general, the degree of "Diplôme Ingénieur" is accepted as a high professional qualification.

Table 1 resumes the main strengths and weaknesses of engineers having gone through the traditional system presented above. The weaknesses should be looked at thoroughly as they would characterize the new engineer profile.

The desirable characteristics for future engineers are resumed in Table 2. The 'new' Engineer will need to interact with people, have an understanding of a multicultural and global environment and several direct experiences working in a team [3].

Table 1. Strengths and weaknesses of a traditional engineer

Strengths	Weaknesses
- Analytical capabilities	- Inability to work in a team
- Design capabilities	- Inter-disciplinary knowledge
- Decision-making including problem solving	- Practical orientation (academics)
- Graphical communication skills	- Commercial orientation
- Discipline, work ethic	- Introspective nature, modesty
	- Ability to use IT
	- Public perception and recognition

Table 2. Desirable characteristics of the 21st Engineers [4]

Traditional attributes	21 st century attributes
- Problem-solving abilities	- Learnability: ability to learn on one's own
- Analytical skills	- Yen for life long learning-continuous education
- Communication skills-both oral, written and graphic	- Ability to muster knowledge from neighboring disciplines
- Ability to relate to practical aspects of Engineering	- Ability to work in a team
- Inter-personal skills	- Exposure to commercial disciplines
- Decision-making skills	- Creativity and Innovation
	- Integrative skills

3. NEW TRENDS IN ENGINEERING EDUCATION

The Algerian Ministry of Higher education is promoting changes both in higher education curricula and their architecture and as a result, most of the universities are dealing with these changes. This led to the adoption of a

system essentially based on two main cycles, undergraduate (Licence/Bachelor) and graduate (Master and/or Doctorate) at which access to the second cycle requires successful completion of the first one. These new study courses are actually run in parallel with the traditional courses which have to vanish in the near future. These changes have been recently applied in Europe through the Bologna Declaration [5] whose common goal is the creation of a European space for High Education which should be completed by the year 2010. The main recommendations of the Declaration are:

- Diversification and series arrangement of High Education.
- Flexibility of the study programs which must be based on the European Credit Transfer System (ECTS).
- Bachelor's study programs should be no shorter than 6 semesters and must include a necessary amount of theoretic and practical courses. They are credited with 180 credit points.
- Master's study programs should be opened for both vertical and horizontal transfer of students. The 2-year Master study program is credited with 120 credit points while a compensatory year is added to students transferring from different study programs and credited with 60 credit points.
- A 3-year PhD program must be available for students interested in research.

However, such study courses would not be successful without better preparing engineers as industrial leaders by placing emphasis on professional skills such as communication, project management, and team leadership. Other characteristics of the program should include excellent scientific equipment for laboratory course modules, group project work, group rooms with multimedia equipment and group rooms for students. The students must get hands-on experience with

modern instrumentation. All these aspects which should be common elements of the engineering programs may be summarized as [6]:

- The program should be based on modern educational units comprising theoretical and experimental course work and lab training.
- Cooperation with industry and research institutions should be encouraged because ensuring proximity to modern engineering problems and familiarization with problem solving procedures in industry and research.
- The program must comprise a broad choice of courses in selected non technical areas important for engineers (legal matters, social sciences, business administration etc.).
- Languages courses for the improvement of writing and comprehensive skills must be offered as part of the program.
- The program must include the opportunity to join a PhD program after graduation.
- Selected students should be given the opportunity to participate in an exchange with diverse partner universities through bilateral agreements.
- Institution and intensification of the mentor (advisor) system in not only helping to solve the day-to-day problems of the students but and mostly in encouraging them to schedule the courses in such a way that they have sufficient time for private activities, especially during the starting semester.

3.1 Effective tools and instructional methods in engineering education

Educational research has shown that learning is enhanced if students are more active and independent, with the lecturer

adopting less of an expository role and more of a facilitating and guiding one. Methods have been developed to insure that learning engineering is never boring. Solutions must be found through interactive learning through trial-and-error exercises conducted at each one's speed, systematic approaches, simulations etc. Percival and Ellington [7] presented a list of eight instructional methods and listed their strengths and weaknesses (c.f. Table 3). It is therefore imperative to choose the right method for the right situation as well as the right tool to enhance it, the quality of student learning being dependent on the effectiveness of the approach used. It is also imperative that all engineering students be taught to use the computer as a tool to aid in their present and future endeavors. Their education must be such that they can built on this foundation and continue to function effectively in future environments of computer technology taking full advantage of its capabilities.

Advances in computing and information technology have seen the emergence of effective tools for engineering education. They mainly include:

- Integrated CAD-CAM emphasizing the use of computers not only in industry but also in learning institutions.
- Virtual reality with its extension to televirtuality.
- Multimedia which can greatly enhance communication and enrich presentation.
- E-learning which offers unique pedagogical opportunities and promotes exploratory and interactive modes of enquiry.
- Web-based experiments concept developed to give the students the

opportunity to perform real experiments in real time on real equipment but over the Internet.

3.2 Quality engineering education and accreditation system in engineering education

'When you can measure what you are speaking about, and express it into numbers, you know something about it, and when you cannot measure it in numbers, your knowledge is of a meager and unsatisfactory kind'. This quote by Lord Kelvin brings out the need for quantification of academic quality. Moreover, globalization has increased the tendency of engineering practice to be international in scope and thus has led to the need for the credentialing of graduate engineers who want to practice in venues other than the one in which they were educated and initially licensed. Thus, accreditation is increasingly seen as the appropriate means of enhancing the quality of engineering education.

It seems therefore essential to set up a board of accreditation able to define and apply a list of criteria for assessment of quality of engineering institutions through a process of self-assessment by the institution and an expert committee visits. The necessity for accreditation would make the institutions strive to put in place mechanisms for addressing quality issues.

In the United States of America, the Accreditation Board for Engineering and Technology (ABET) has been the major quality assurance mechanism in the US for engineering education since the 1930's.

However, in the past several years, ABET has made a major change in its evaluation criteria moving from technique specifications to outcomes assessment. Its 'Criteria 2000' is based upon institutional self study and goal setting against which it will be evaluated, continuous improvement requirements for accredited programs, and detailed assessment of the outcomes of the engineering programs as the fundamental criterion for accreditation.

Table 3. Key characteristics of some of the main instructional methods [7]

Method	Strengths	Weaknesses
Directed study of material in textbooks	<ul style="list-style-type: none"> - Effective method to teach basic facts - Allows learner to work at own pace - Needs no specialized facilities 	<ul style="list-style-type: none"> - Requires careful planning and structuring - Dependent on suitable text being available in sufficient numbers for the class size - Not suitable for achieving many higher cognitive and non-cognitive objectives
Programmed text	<ul style="list-style-type: none"> - Same basic advantages as directed study of books - Allow learners to interact with the material 	<ul style="list-style-type: none"> - Preparing suitable material is very time consuming - Not suitable for achieving many higher cognitive and non-cognitive objectives
Self-instruction using audio/visual media and compute	<ul style="list-style-type: none"> - Enables a wide range of educational objectives to be achieved (especially lower cognitive) - Allows learner to work at own pace - Can save teachers from having to carry out repetitive and time consuming work - Allows interaction between the learner and instructional program and can be highly stimulating 	<ul style="list-style-type: none"> - Ideal ready-made courseware seldom available - Preparation can be time consuming, expensive and requires specialist skills - Not suitable for achieving many higher cognitive and non-cognitive objectives - Cannot be used unless suitable hardware is available, which can be expensive
Lectures and similar expository techniques, such as demonstration	<ul style="list-style-type: none"> - Cost effective in terms of staff/student ratio - Strong in achieving lower cognitive objectives - Generally popular with students and staff - Ideal for introductory or overview process 	<ul style="list-style-type: none"> - Strongly dependent on the skills of lecturer - Weak in achieving most higher cognitive and effective objectives - Not suitable for achieving psychomotor objectives or developing communication or interpersonal skills - Student involvement low or non-existent - Pace controlled by teacher - Most lectures are too long for the concentration span of students
Buzz sessions and similar short small Group exercises	<ul style="list-style-type: none"> - Excellent method of introducing variety into a lecture, thus helping to maintain student attention - Can achieve a wide range of objectives, both cognitive and non-cognitive - Students are actively involved in the lesson - Permits feedback to take place 	<ul style="list-style-type: none"> - Only useful in a supportive role as a part of a larger lesson - Requires a skilled facilitator
Class discussions, seminars and tutorials	<ul style="list-style-type: none"> - Same basic advantages as buzz sessions - In addition, the greater length allows a wider range of objectives to be achieved, often of a high level - Enables relevant topics to be examined in depth 	<ul style="list-style-type: none"> - Danger that not all the class takes an active part - Can cause timetabling problems if a class has to split up - Danger of the tutor dominating discussions
Participative exercise of games/simulation/case study type	<ul style="list-style-type: none"> - Can be used to achieve a wide range of objectives, both cognitive and non-cognitive, often of a high level - High student involvement - Stimulating and motivating if properly designed - Ideal for cross-disciplinary work 	<ul style="list-style-type: none"> - Only useful in a supportive or illustrative role - Can be difficult to fit in, especially with long exercises - Must be relevant to be of educational value - Requires briefing and debriefing skills
Group projects	<ul style="list-style-type: none"> - Suitable for developing a wide range of objectives, both cognitive and non-cognitive, often of a high level - Ideal for developing interpersonal skills - Ideal for cross-disciplinary work 	<ul style="list-style-type: none"> - Danger that not all members will pull their weight - Assessment of contribution made by individual student may be problematic

Engineering programs must demonstrate that their graduates have [8]:

- An ability to apply knowledge of mathematics, science and engineering.
- An ability to design and conduct experiments, as well as to analyze and interpret data.
- An ability to design a system, component, or process to meet desired needs.

- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate, and solve engineering problems.
- An understanding of professional and ethical responsibility.
- An ability to communicate effectively.
- The broad education necessary to understand the impact of engineering solutions in a global and societal context.
- A recognition of the need for, and an ability to engage in life-long learning.
- A knowledge of contemporary issues.
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Several countries have been developing engineering accreditation boards. In Germany and in order to assist in the development of the new programs implemented (bachelors plus masters pattern) and to evaluate and certify their quality, a new Accreditation Agency for Programs in Engineering and Computer Science (ASII) has been established. A new Japan Accreditation Board for Engineering Education has been established to provide quality assurance as new engineering programs are developed and implemented. It tries to respond to the need for Japanese engineering graduates to be prepared for more self directed career development, and that they be prepared for practice in the global marketplace. In Jordan, The Council on Higher Education has developed and implemented detailed prescriptive specifications for areas such as faculty/student ratios, laboratory equipment and space, libraries, and financial stability in order to assure that quality is provided in private universities offering degree programs within its borders. Finally, Both Accreditation Board for Engineering and Technology

(ABET) and the Canadian Engineering Accreditation Board (CEAB) have conducted workshops and training efforts in Latin America to assist in the development of engineering accreditation systems. This led to the development of the Consejo de Acreditacion de la Ensenanza de la Ingenieria (CACEI) in Mexico.

4. CONCLUSIONS

Learning, knowledge and education are the major themes of the 21st Century. The demand for engineering training will continue to grow rapidly. As such, higher technical institutions need to set themselves the goal of making engineering training ever more efficient and solutions are required to effectively prepare engineers to function in a global community with ethical and professional responsibilities. The L-M-D study course programs applied recently in Algeria has been highly influenced by the Bologna Declaration which set up the 3-2(3)-3 program. Such developments would not achieve success without modern instructional methods and the effective tools to enhance them. Moreover, action should be taken to developing great staff that can effectively use the diverse instructional methods and tools.

Finally, a quality plan should be implemented, involving quality in engineering programs. IT technologies should also be used to support quality improvement, cost effectiveness and decision making. Furthermore, a move from quality assessment to quality certification should be considered as a strategic goal, accreditation being an effective mechanism for effecting and assuring ongoing quality in engineering programs in a country.

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